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Control-Display mapping with three translational degrees of freedom

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Bij het mappen van deze bewegingen kunnen twee principes onderscheiden worden. Het eerste levert een mapping waarbij de bewegingen van het bedieningsmiddel en het object altijd parallel zijn in de 3D ruimte (ruimtelijke-beweging mapping). Het tweede leidt tot een mapping waarbij de bewegingen gelijk zijn ten opzichte van het vlak waarin het bedieningsmiddel gepositioneerd, en het display georiënteerd is (referentievlak mapping). Beide vlakken zullen vaak niet parallel zijn, bv. als een monitor op een tafel staat waarin het bedieningsmiddel is gemonteerd. In die gevallen zullen beide principes tot een verschillende mapping leiden.

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Belangrijkste resultaat van het experiment is het voordeel van de ruimtelijke - bewegings mapping. Gesuggereerd wordt dat het verschil met het eerdere experiment verklaard kan worden door de aanwezigheid van de diepte cues. Deze kunnen ervoor gezorgd hebben dat de bestuurders hun taak ook echt als 3D taak ervaren hebben.

Het resultaat kan belangrijke consequenties hebben voor de ontwerpers van zulke systemen. De compatibele relatie tussen control en display hangt dus af van de beschikbaarheid van visuele diepte cues in het display. Als deze niet aanwezig zijn zullen bestuurders een referentie-vlak mapping verkiezen (een 2D muis met een derde dimensie toegevoegd in de situatie waarin het besturingsmiddel in, en de monitor op de operator tafel is geplaatst). Wanneer deze cues echter wel aanwezig zijn, zal de voorkeur uitgaan naar het ruimtelijke-beweging principe, hetgeen zal leiden tot een andere mapping.

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Situations in which the human operator must control three translational degrees of freedom are common in, for example, control of robot arms, remotely controlled cameras, and tele-surgery. Often, the operator has no direct view on the controlled object, but receives information on the motions of the object via a camera - monitor system or a simplified graphical display. In the design of such systems, it is important that the mapping of the motions directions of the input device and the controlled object are compatible for the human operator. A compatible relation will lead to faster reaction times, faster learning and less errors. For this relation, two mapping principles may be distinguished. The first is a mapping in which the motions of the input device and the controlled object are always parallel in 3D space (spatial-motion mapping). The second principle is a mapping in which the motions are parallel by comparison with the ground planes they are located or displayed in (reference-plane mapping). These ground planes often are not parallel, for example a monitor placed on the operator table in which the control is located. When the ground plane of the device and the object are not parallel, both principles will lead to a different mapping. The literature on tasks with two degrees of freedom shows that reference-plane mapping is the more compatible mapping principle. However, the question is whether these results are valid for 3D tasks as well. Research on control - display mapping for three translational degrees of freedom is scarce. A previous experiment at the TNO Human Factors Research Institute showed an advantage of reference-plane mapping. Nonetheless, there are indications that this advantage is caused by the restrained 3D visual depth cues, which encouraged subjects to experience the task as a 2D task with a third dimension added. The present experiment uses the same positioning task, but with a display including high quality depth cues. This may be seen as a simulation of indirect viewing via camera - monitor systems, instead of a simplified graphical representation.
The main result found was the beneficial effect of spatial-motion mapping. It was suggested that this effect differs from the effects found in the former experiment, because of the presence of high-quality visual depth cues. These cues may have encouraged subjects to experience the task as a real 3D task. This result may have serious implications for the designers of systems with three translational degrees of freedom. The compatible relation between motions of the control device and the controlled object may be largely dependent on the availability of visual depth cues in the display. When these cues are not available, operators may prefer a reference-plane mapping. But when these cues are available, the spatial-motion principle is preferred, which leads to a different mapping.

16. DESCRIPTORS Display Man-computer interface Man-equipment compatibility Mouse (device)	IDENTIFIERS Perspective display Manual control

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Het resultaat kan belangrijke consequenties hebben voor de ontwerpers van zulke systemen. De compatibele relatie tussen control en display hangt dus af van de beschikbaarheid van visuele diepte cues in het display. Als deze niet aanwezig zijn zullen bestuurders een referentie-vlak mapping verkiezen (een 2D muis met een derde dimensie toegevoegd in de situatie waarin het besturingsmiddel in, en de monitor op de operator tafel is geplaatst). Wanneer deze cues echter wel aanwezig zijn, zal de voorkeur uitgaan naar het ruimtelijke-beweging principe, hetgeen zal leiden tot een andere mapping.

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SUMMARY

Situations in which the human operator must control three translational degrees of freedom are common in, for example, control of robot arms, remotely controlled cameras, and telesurgery. Often, the operator has no direct view on the controlled object, but receives information on the motions of the object via a camera - monitor system or a simplified graphical display. In the design of such systems, it is important that the mapping of the motions directions of the input device and the controlled object are compatible for the human operator. A compatible relation will lead to faster reaction times, faster learning and less errors. For this relation, two mapping principles may be distinguished. The first is a mapping in which the motions of the input device and the controlled object are always parallel in 3D space (spatial-motion mapping). The second principle is a mapping in which the motions are parallel by comparison with the ground planes they are located or displayed in (reference-plane mapping). These ground planes often are not parallel, for example a monitor placed on the operator table in which the control is located. When the ground plane of the device and the object are not parallel, both principles will lead to a different mapping.

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Control-display mapping bij drie translatoire vrijheidsgraden

J.B.F. van Erp, A. Oving en J.E. Korteling

SAMENVATTING

Systemen waarin een bestuurder drie translatoire vrijheidsgraden moet besturen zijn gemeengoed in ondermeer de robotica, afstandsbestuurde camera's, en tele-chirurgie. In deze situaties heeft de bestuurder vaak geen direct zicht op het bestuurde object, maar ziet de bewegingen ervan via een camera - monitor systeem, of via een versimpeld grafisch display. Bij het ontwerpen van zulk soort systemen, is het belangrijk om een compatibele relatie tussen de bewegingen van het bedieningsmiddel en het object te bewerkstelligen. Een compatibele relatie leidt tot betere prestaties: snellere reactietijden, minder fouten en een sneller leerproces.
Bij het mappen van deze bewegingen kunnen twee principes onderscheiden worden. Het eerste levert een mapping waarbij de bewegingen van het bedieningsmiddel en het object altijd parallel zijn in de 3D ruimte (ruimtelijke-beweging mapping). Het tweede leidt tot een mapping waarbij de bewegingen gelijk zijn ten opzichte van het vlak waarin het bedieningsmiddel gepositioneerd, en het display georiënteerd is (referentievlak mapping). Beide vlakken zullen vaak niet parallel zijn, bv. als een monitor op een tafel staat waarin het bedieningsmiddel is gemonteerd. In die gevallen zullen beide principes tot een verschillende mapping leiden.
Uit de literatuur naar taken met twee vrijheidsgraden blijkt dat referentievlak mapping het meer compatibele principe is. De vraag is echter of deze resultaten ook voor taken met drie vrijheidsgraden geldig zijn. In een eerder experiment bij TNO Technische Menskunde werd geconcludeerd dat referentievlak mapping ook bij 3D taken tot betere prestaties leidt. Er zijn echter indicaties dat dit voordeel werd veroorzaakt door het gebrek aan visuele diepte cues in het display. Hierdoor konden bestuurders de taak ervaren als een 2D muis besturingstaak waaraan een derde dimensie is toegevoegd. Het huidige experiment gebruikt dezelfde 3D positioneringstaak, maar met een display waaraan hoogwaardige diepte cues zijn toegevoegd. Dit lijkt dus op een simulatie van indirect zicht via een camera - monitor systeem.
Belangrijkste resultaat van het experiment was het voordeel van de ruimtelijke - bewegings mapping. Gesuggereerd wordt dat het verschil met het eerdere experiment verklaard kan worden door de aanwezigheid van de diepte cues. Deze kunnen ervoor gezorgd hebben dat de bestuurders hun taak ook echt als 3D taak ervaren hebben.
Het resultaat kan belangrijke consequenties hebben voor de ontwerpers van zulke systemen. De compatibele relatie tussen control en display hangt dus af van de beschikbaarheid van visuele diepte cues in het display. Als deze niet aanwezig zijn zullen bestuurders een referentie-vlak mapping verkiezen (een 2D muis met een derde dimensie toegevoegd in de situatie waarin het besturingsmiddel in, en de monitor op de operator tafel is geplaatst). Wanneer deze cues echter wel aanwezig zijn, zal de voorkeur uitgaan naar het ruimtelijke-beweging principe, hetgeen zal leiden tot een andere mapping.

1 INTRODUCTION

Control devices in existent man-machine systems often have one or two degrees of freedom (DOF), like volume knobs on radios, or handles of a bulldozer. A degree of freedom in this instance, is a translation along the x, y, or z axis, or a rotation around one of them. When more than one degree of freedom is involved in a task, integrating the required degrees of freedom in one control device (and accompanying display) may improve task performance. In this situation, the control order of the integrated DOF's must be the same (i.e. Chernikoff & Lemay, 1963; Fracker & Wickens, 1989).

A control device in which three or more DOF's are integrated may be advantageous in tasks in which objects with three or more DOF's must be controlled. One of the areas in which this is common is remote or tele-control, including the control of unmanned platforms and robot-arms, and remote medical surgery. However, these applications often allow only indirect viewing of the manipulated objects via (2D) monitors. In this case, mapping of the motions of the control device in 3D and of the manipulated object depicted on a 2D display may be accomplished in different ways, which are more or less compatible. Compatibility in this regard is defined as the similarity between the true mapping, and the expected mapping. Compatibility is enlarged when the true mapping is expected by a larger proportion of the population (Fitts & Seeger, 1953; Kornblum, Hasbroucq & Osman, 1990).

The importance of a compatible control-display mapping is evident. With a compatible relation, performance will be better than with a less compatible or incompatible relation. This is expressed in decreasing reaction times, decreasing number of errors, and faster learning (i.e. Duncan, 1977; Beringer & Worringham, 1992; Fitts & Deininger, 1954; Fitts & Seeger, 1953; Miller, 1985; Wayman, 1993). Furthermore, with incompatible relations, performance is more sensitive to increased workload (Loveless, 1962; Andre & Wickens, 1992; Wayman, 1993). This may eventually lead to operators applying the expected relation between control and display.

Control-display mapping for three translational degrees of freedom

Mapping of translational degrees of freedom concerns motion compatibility: the (direction of) motions of the control device, and the (direction of) motions of the controlled object on the display (Kornblum, Hasbroucq & Osman, 1990). Involving linear controls and displays in 2D, research shows that a compatible mapping means that motions of stimulus and response are parallel when possible (Fitts & Deininger, 1954; Loveless, 1962; Andre & Wickens, 1992; Simon, 1969). However, the field of motion compatibility between 3D control devices and (2D) displays knows little research.

In general, for the mapping of three translational DOF, one can distinguish two mapping principles:

1 **spatial-motion mapping.** Contrary to 2D tasks, in 3D tasks, it is always possible to implement a configuration in which all motions are parallel, despite the orientation of both

control and display. Moving the control forward results in a forward motion on the display, moving the control upward results in a upward motion of the object on the display, etc. This principle is analogous to the principle of geographical compatibility as introduced by Beringer and Worringham (1992) in their 2D task, and resembles condition A in the research of Spragg, Finck, and Smith (1959), see Figure 1C and 2A.

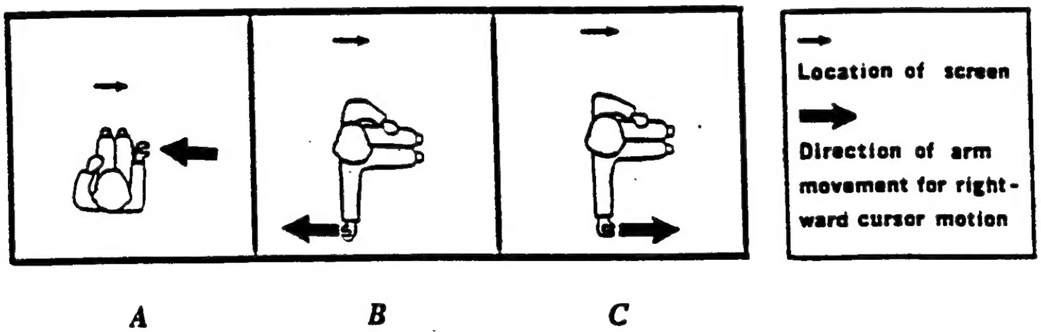

Fig. 1 Three principles of compatibility as defined by Beringer and Worringham (1992): A muscle synergy, B virtual visual field compatibility, C geographical mapping.

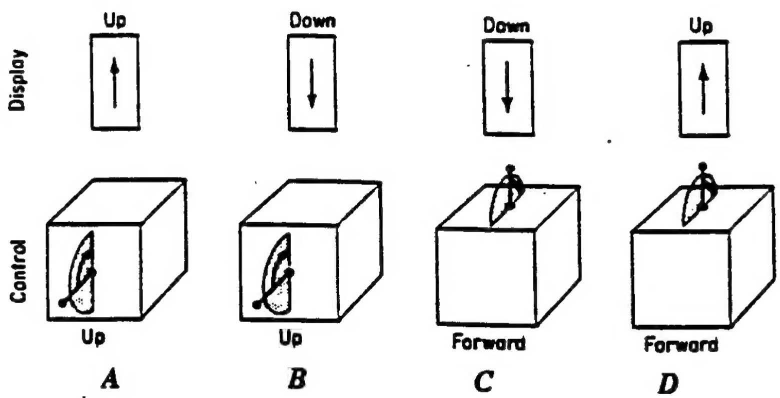

Fig. 2 The four control display configurations used by Spragg, Finck and Smith.

2 **reference-plane mapping.** A second principle is based on mapping the motions of the device in relation to the plane in which it is located (as seen by the operator), on the motions of the controlled object in relation to the plane of the display (see Figure 1B). Only if both are located in the same plane, motions of device and object are parallel and in accordance with spatial-motion mapping. However, both planes will often not be parallel (for example control device in a horizontal plane, and monitor in a vertical plane), and both mapping principles lead to a different mapping (see Figure 3).

The experiments of Beringer and Worringham (1992), Buiël and Breedveld (1995), and Van Erp, Oving and Korteling (1996), showed that performance in the reference-plane mapping is better than with spatial-motion mapping in 2D and 3D tasks, respectively. Other indications for the compatibility of reference-plane mapping is found in the experiments of Spragg, Finck and Smith (1959), and Wayman (1993). When control and display orientation are different (configuration C and D in Figure 2), direct mapping of the control plane with the display plane leads to better performance. Best performance was reached with configuration A, which is compatible with both the spatial-motion and the reference-plane mapping principles.

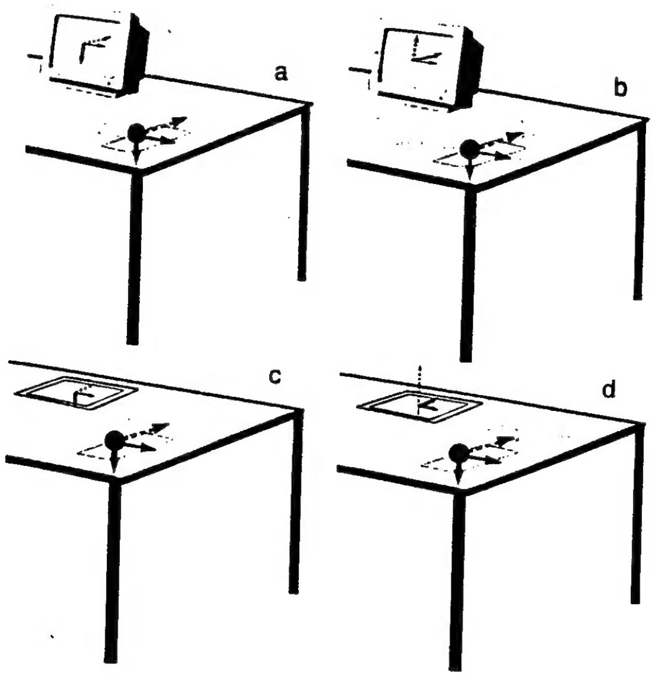

Fig. 3 Example of control-display mapping for different orientations of control device and display used in the experiment of Van Erp, Oving and Korteling (1996): A and C spatial-motion mapping present, B and C reference-plane mapping present.

The present experiment

The present experiment focuses on control-display mapping for three translational degrees of freedom. In a previous experiment (Van Erp et al., 1996), it was shown that reference-plane mapping led to faster and more efficient control in a 3D positioning task. However, the 2D display used included no other depth cues than relative size and interposition. Therefore, participants might have experienced the task as a normal 2D mouse positioning task, with the third dimension added by moving the 3D mouse up and down. This strategy may explain the advantage of the reference-plane mapping. The present experiment again concerns a 3D positioning task, but with a (2½D) display with extended depth cues, including three dimensional cubes, linear perspective, texture gradient, interposition, relative size, and haze. It was hypothesized that participants would encounter the task as a real 3D task, and not as a 2D task

with an added dimension. The environment could be depicted in three forms: no environment, forward looking, and downward looking (see Figure 4). The first environment only contained two cubes, the last two environments also contained four walls and a background. Most distinctive difference between the last two was the orientation of the bricks and the colour of the background. These differences were accompanied with appropriate instructions. This was expected to locate graphity or the plane of reference in a different orientation, the floor for the forward looking, and the bottom for the downward looking environment, respectively. Hypothesis was that task performance would be enhanced when control display mapping was supported by the environment imposed reference plane. In this case the reference-plane mapping uses the screen as reference and would be enhanced by the downward looking environment and the spatial motion mapping would be enhanced by the forward looking environment. In the results, this would lead to an interaction between control mode and display mode.

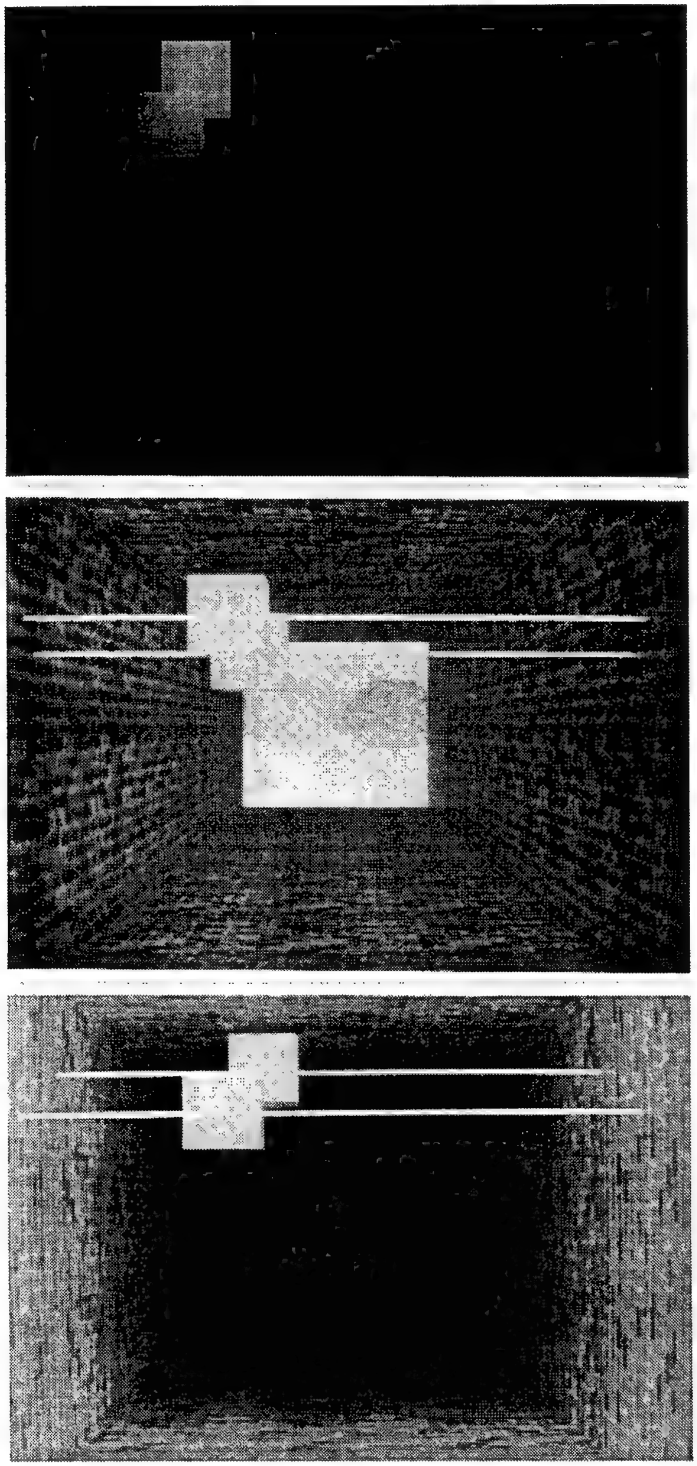

Fig. 4 The three environments used in the present experiment: a. no environment, b. forward looking, c. downward looking.

2 METHODS

2.1 Subjects

Sixteen male students were recruited from the standard TNO subjects pool. Mean age was 21 (SD 2 years, range 19–26). All subjects had normal, or corrected to normal sight, were right-handed, had no experience with similar experiments, and were paid for their participation.

2.2 Task and Instruction

Subjects' task was a positioning task in three dimensions. The display depicted two cubes of the same size, one green and one red. The green cube was positioned at a fixed location, the position of the red one was controlled by the subject by means of a so-called 3D mouse. Subjects were asked to position the red cube in the same location as the green cube in the depicted 3D space. Instructions were: 1. to position this cube as fast as possible, and 2. to reach the green cube via the shortest way. Depending on the environment depicted in the display, the following additional information could be given: forward looking environment: "you are working in a corridor", downward looking environment: "you are working in a shaft". Complete instructions in Dutch are given in the Appendix.

2.3 Instrumentation

The experiment was carried out in the TNO Human Factors Research Institute Remotely Piloted Vehicle simulator. This simulator is devised to simulate unmanned missions and remote control operations, and is described elsewhere (Korteling & Van Breda, 1994).

Image generator

A one-channel ESIG 2000 was used for the generation of the visual stimuli. The edges of the controlled (red) and target cubes (green) were 48 cm. All sides had different saturations. The green target cube had a transparency of 0.5, so outlines of the controlled cube were always visible. In the forward and downward looking environments, both cubes had sticks attached which connected the cubes in horizontal orientation with the walls. These sticks were square with 2 cm diameter. The four walls were textured with bricks (12 bricks in 64×64 pix.) in the forward and downward environments. The visual environment measured $4 \times 3.5 \times 18$ m (width $\times$ height $\times$ length). In all display modes, a glass box measuring $3.5 \times 3.5 \times 6.75$ m was simulated, which was not visible, but bordered the available space to move the cubes in. In the no-environment condition, the walls and background were black. In the forward looking environment, the bricks in the side walls were orientated in the depth direction, and the background consisted of a view on trees and a horizon. In the downward condition, all bricks were orientated perpendicular to the depth direction, and the background was plain

black. Visibility was 50 km in the forward looking environment, 0.8 km in the downward looking environment, and 20 km in the no-environment condition. All objects were fixed shaded. The visual stimuli were generated for a projection distance of 45 cm ($43° \times 33°$, $H \times V$).

Stimuli

For each trial, different initial positions for cursor and target were generated by choosing an arbitrary point on a sphere as initial position for the target. The point of reference of the display was chosen as centre of the sphere, initial position of the cursor was found by projecting the position of the target through this centre. Initial points were chosen such, that minimum distance travelled on each axis was 80 cm. Furthermore, taken over all trials, the total distance to travel was equal in each dimension. To balance the direction of the required motion on each axis, initial positions of target and cursor were switched, and added to the list of trials. The total number of stimulus pairs was 90, used twice in every display mode (randomized order). Between two consecutive trials, the screen was black for 1.5 s.

Instrumentation

The control device was connected to a LIJN 80486-66 PC, which served as model and calculated the parameters for the image generator. This PC also registered stimulus data, and mouse input, and stored the data. A second LIJN 80486-33 PC was used as clock; update and sample frequency of the total system was set at 30 Hz.
As control device in the experiment, a commercial 6 degree of freedom space master® was used. This device consists of a ball, mounted on a stationary platform. By subjecting force/torsion on the ball, one moves the object. This also results in small postponement of the ball in relation to the platform: 4.5 mm for translations. The ball of the space master is spring-centred. Because of the availability of proprioceptive feedback, with such an elastic control, one performs better than with an iso-metric device (Zhai & Milgram, 1993; Zhai, 1993). The cursor was controlled with linear speed control (first order), maximum speed (in 3D) was 1.8 m/s. In each of the conditions, the mouse was located 5 cm from the right side of the monitor.

2.4 Statistical design

Subjects were randomly divided into two control mode groups of eight subjects each. The first group worked with a control - display mapping according to the reference-plane mapping (see Figure 3B), the second group worked with a control - display mapping according to the spatial-motion mapping (Figure 3A). Both groups completed the task under three levels of display mode: no environment, forward view, and downward view, order balanced. In each of these three levels a total of 180 trials was completed, divided over two sessions.

Dependent variables

During the experiment, x, y, and z coordinates of the controlled cursor were recorded (30 Hz sampling frequency). From this raw data, two dependent performance measures were extracted: total time per trial, and total distance travelled per trial. This last variable is a measure for task efficiency (see Van Erp, Kappé & Korteling, 1996). Correct positioning was defined as keeping the cursor for 0.5 s within an area around the target (margin 15 cm). If a subject could not complete a trial within 60 s, the trial was interrupted, and the next started. In this case, 60 s was taken as score.

2.5 Procedures

Subjects came in pairs and worked consecutively. After arrival they were randomly assigned in one of the control mode groups. They simultaneously were introduced on the general nature of the experiment, their payment, time schedule etc. Thereafter, they received a written instruction on the details of the task, and their particular control mode. Individual training consisted of free moving of the controlled cube in the first display mode (one minute, target cube not visible), followed by 6 trials in fixed order. During this training the instructor sat next to the subject and explained the control and display. After this initial training the experiment began, and subjects completed the trial in blocks of 90 trials. During the experiment no feedback was given.

3 RESULTS

Time to completion

Results of the ANOVA on the time to completion is given in Table I.

Table I ANOVA on time to completion.

Effect	DF	F	p
display mode (d)	2,8592	0.53	.587
control mode (c)	1,8592	230.11	.000
d x c	2, 8592	5.84	.003

The interaction display mode × control mode is depicted in Figure 5. A post hoc test on this interaction showed no other significant differences than caused by the main effect of control

mode: spatial-motion mapping (mean 4.81 s) led to 10% faster task completion than reference-plane mapping (mean 5.34 s).

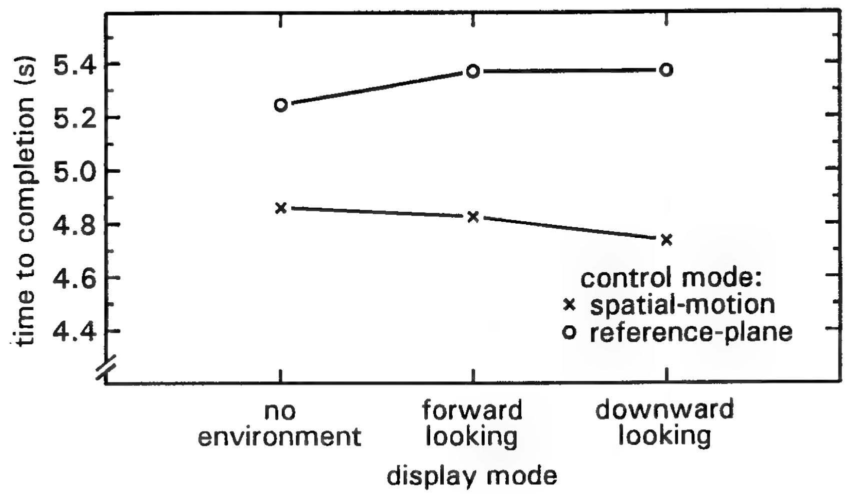

Fig. 5 Interaction of display mode and control mode for time to completion.

Distance travelled

The results of the analysis on the distance travelled are presented in Table II.

Table II ANOVA on distance travelled.

Effect	DF	F	p
display mode (d)	2,8592	8.52	.003
control mode (c)	1,8592	0.09	.762
d × c	2, 8592	1.34	.261

Only the main effect of display mode reached significance. Mean distance travelled for the three levels was as follows: no environment: 4.27 m, forward view: 4.37 m, downward view: 4.30 m. The post hoc test showed that distance travelled in the forward view was significantly higher than in the other two display modes.

4 DISCUSSION

Time to completion

The results found on control mode differ from the results found in a previous experiment (Van Erp, Oving & Korteling, 1997). In the former experiment, no extensive depth cues were available in the 2D display, and an advantage of reference-plane mapping was present on time to completion and distance travelled in a positioning task. In the present experiment, more extensive cues were present, which resulted in better results in the spatial-motion mapping on time to completion. An explanation for the effect found in the first experiment may be that subjects experienced the task as a 2D mouse control task, with a third dimension added. This would lead to an advantage for the reference-plane mapping. The visual cues given in the present experiment probably have encouraged subjects to feel the task as really operating in a 3D environment, which may therefore lead to advantage for a mapping in which motions are parallel in 3D space.
This indicates that, when no extensive 3D cues are available, subjects tend to prefer a mapping which is learned for controlling a mouse on a computer screen, and simple add the third dimension. This leads to a reference-plane mapping. When the task environment contains more 3D cues, the preferred mapping is the spatial-motion mapping, which is compatible when the 3D control space is experienced as congruent with the 3D object space.

The results may have serious consequences for the design of manual controlled systems without direct viewing. When the manipulated object is viewed or presented to the operator in a 3D environment, for example by video cameras, a spatial-motion mapping is preferable. However, when only a simplified graphical representation is seen, operators may experience their task more as a 2D task with one additional translational degree of freedom. In this situation, the reference-plane mapping seems to be preferable.

There is no difference between the forward and downward looking environment. This is in accordance to the hypothesis, we expected no inherent advantage of one of the configurations, because they were matched as good as possible on the characteristics and quality of the visual cues given during the task. However, we expected that both environments, in combination with instructions given, would support one control-display mapping, i.e. the compatible one, more than the other. Although there is a trend present concerning this interaction, the post-hoc test could not reveal the expected pattern. This means that with sufficient 3D cues present, the spatial-motion display mapping leads to faster completion times, despite the nature of the presented environment.

Distance travelled

On the distance travelled (task efficiency), we found a main effect of display mode only. The post-hoc Tukey test showed that distance travelled in the forward looking environment is significantly larger than in the other two environments. A main effect for this variable was

not expected, although one might hypothesize an advantage of the forward and downward looking environments over the empty world. An explanation for this effect is not available.

The fact that this interaction is not found may be due to the fact that the differences between both displays are only small, because of the need to minimize the differences in the quality of the visual information provided by the displays. The hypothesized interaction between control mode and display mode is not found on time to completion or distance travelled. This means that the availability of extensive 3D cues alone is sufficient to enhance the spatial-mapping mode, despite the environment in which the task must be carried out. This implies that the orientation of the display (or for example orientation of the camera) has no implications.

Recommendations

A manually controlled system with 3 or more (translational) degrees of freedom requires the designer to carefully consider the possibilities of mapping the motions of the input device on the motions of the controlled object. Better performance will be reached when this mapping is more compatible, i.e. in accordance with natural indications and/or what operators expect. The present research project shows that the view on the controlled object plays an important role in this design. On the basis of the present and previous experiment, one may conclude that the presentation of a 3D environment in the visual display may lead to an other preferred mapping than a simplified 2D graphical representation. In the last instance, operators prefer a reference-plane mapping, in which motions are parallel in comparison with their ground plane. However, when extensive 3D cues are available (for example with a camera-monitor system), operators prefer a spatial-motion mapping, in which the motions of the control device and the control object are always parallel in 3D space. This mapping is preferred despite a difference in orientation of the ground plane or visual environment. It is recommended to adjust the control display mapping according to the visual display available.

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Soesterberg, 29 May 1997

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APPENDIX Complete instructions in Dutch

Er verschijnen twee gekleurde kubussen op het beeldscherm: een groene en een rode kubus. De rode kubus kun je besturen met een 3D-muis, de groene blijft stilstaan. Bij deze taak is het de bedoeling dat je de rode kubus ***zo snel mogelijk*** naar de groene kubus stuurt. Daarnaast moet je ook proberen om de groene kubus in een ***zo recht mogelijke lijn*** te bereiken. Hierbij moet de rode kubus ***in*** de groene kubus worden geplaatst. De kubussen verdwijnen van het scherm zodra je de rode kubus goed genoeg in de groene kubus hebt geplaatst.

Hierbij kun je in de links-rechts en omhoog-omlaag richting van het scherm bewegen. Daarnaast kun je ook in de diepte-richting bewegen. Welke kubus van de twee verder van je af ligt (meer in de diepte), kun je zien doordat deze kubus kleiner is. Daarnaast kan de kubus die dichter bij ligt (en dus groter is), de andere kubus geheel of gedeeltelijk afdekken, waardoor de laatste kubus maar gedeeltelijk of helemaal niet is te zien.

óf (bij spatial motion mapping)

Wanneer je de bol van de muis naar links beweegt, beweegt ook de rode kubus naar links, en beweeg je de bol naar rechts dan gaat ook de kubus naar rechts. Om de kubus in de diepte te sturen (kleiner te maken) beweeg je de bol naar voren (van je af). Om de kubus naar je toe te halen (groter te maken) beweeg je de bol naar je toe. Om de kubus omhoog te bewegen op het scherm, trek je de bol omhoog. En om de kubus omlaag te bewegen op het scherm, druk je de bol naar beneden.

óf (bij reference-plane mapping)

Wanneer je de bol van de muis naar links beweegt, beweegt ook de rode kubus naar links, en beweeg je de bol naar rechts dan gaat ook de kubus naar rechts. Om de kubus in de diepte te sturen (kleiner te maken) beweeg je de bol naar beneden. Om de kubus naar je toe te halen (groter te maken) beweeg je de bol naar boven. Om de kubus omhoog te bewegen op het scherm, beweeg je de bol naar voren (van je af). En om de kubus omlaag te bewegen op het scherm, beweeg je de bol naar je toe.

Bij deze taak worden drie verschillende omgevingen gebruikt. Zo voer je de taak een keer uit in een put, waarbij je loodrecht naar beneden kijkt (je kijkt dus naar de bodem van de put). Daarnaast voer je de taak een keer uit in een gang, waarbij je in de verte een horizon ziet. Je voert de taak ook nog een keer uit in een omgeving waarin je alleen de kubussen ziet; hierbij is de rest van het scherm zwart.

Wanneer de test wordt gestart, verschijnen er twee kubussen direct op het scherm. Het is dus belangrijk dat je dan al je hand in de buurt van de muis hebt liggen, zodat je direct kunt

reageren. Om te wennen aan de muis, krijg je eerst alleen de rode kubus te zien. Hiermee kun je de verschillende bewegingen even uitproberen. De taak is afgelopen als er geen nieuwe kubussen meer op het beeldscherm verschijnen.

De bedoeling is: de rode kubus zo ***snel*** en zo ***direct*** mogelijk naar de groene kubus sturen!!

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTES))

Situations in which the human operator must control three translational degrees of freedom are common in, for example, control of robot arms, remotely controlled cameras, and tele-surgery. Often, the operator has no direct view on the controlled object, but receives information on the motions of the object via a camera - monitor system or a simplified graphical display. In the design of such systems, it is important that the mapping of the motions directions of the input device and the controlled object are compatible for the human operator. A compatible relation will lead to faster reaction times, faster learning and less errors. For this relation, two mapping principles may be distinguished. The first is a mapping in which the motions of the input device and the controlled object are always parallel in 3D space (spatial-motion mapping). The second principle is a mapping in which the motions are parallel by comparison with the ground planes they are located or displayed in (reference-plane mapping). These ground planes often are not parallel, for example a monitor placed on the operator table in which the control is located. When the ground plane of the device and the object are not parallel, both principles will lead to a different mapping. The literature on tasks with two degrees of freedom shows that reference-plane mapping is the more compatible mapping principle. However, the question is whether these results are valid for 3D tasks as well. Research on control - display mapping for three translational degrees of freedom is scarce. A previous experiment at the TNO Human Factors Research Institute showed an advantage of reference-plane mapping. Nonetheless, there are indications that this advantage is caused by the restrained 3D visual depth cues, which encouraged subjects to experience the task as a 2D task with a third dimension added. The present experiment uses the same positioning task, but with a display including high quality depth cues. This may be seen as a simulation of indirect viewing via camera - monitor systems, instead of a simplified graphical representation.
The main result found was the beneficial effect of spatial-motion mapping. It was suggested that this effect differs from the effects found in the former experiment, because of the presence of high-quality visual depth cues. These cues may have encouraged subjects to experience the task as a real 3D task. This result may have serious implications for the designers of systems with three translational degrees of freedom. The compatible relation between motions of the control device and the controlled object may be largely dependent on the availability of visual depth cues in the display. When these cues are not available, operators may prefer a reference-plane mapping. But when these cues are available, the spatial-motion principle is preferred, which leads to a different mapping.

16.	**DESCRIPTORS** Display Man-computer interface Man-equipment compatibility Mouse (device)	**IDENTIFIERS** Perspective display Manual control

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